DOE/NASA CONTRACTOR REPORT

DOE/NASA CR-150735

SOLAR HEATING AND COOLING SYSTEM DESIGN AND DEVELOPMENT (Status Summary through December 1977)

Prepared by

General Electric Company
Post Office Box 8555
Philadelphia, Pennsylvania 19101

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For the U. S. Dept of Energy

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U.S. Department of Energy

Solar Energy

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SECTION 1

INTRODUCTION

This project, a part of the Marshall Space Flight Center program for the development of solar heating and combined solar heating and cooling systems[1], involves the complete design and development of marketable systems for single family and commercial applications and the delivery, installation, and monitoring of the prototype systems. The development of the two types of systems is proceeding in parallel with selected commonality of system elements. The time required for the development of the combined heating and cooling systems is greater than for the heating systems, so the heating systems are being installed while development of the cooling subsystem continues. It is convenient to discuss the systems separately in the sections of this document.

A summary program schedule is shown in Figure 1-1.

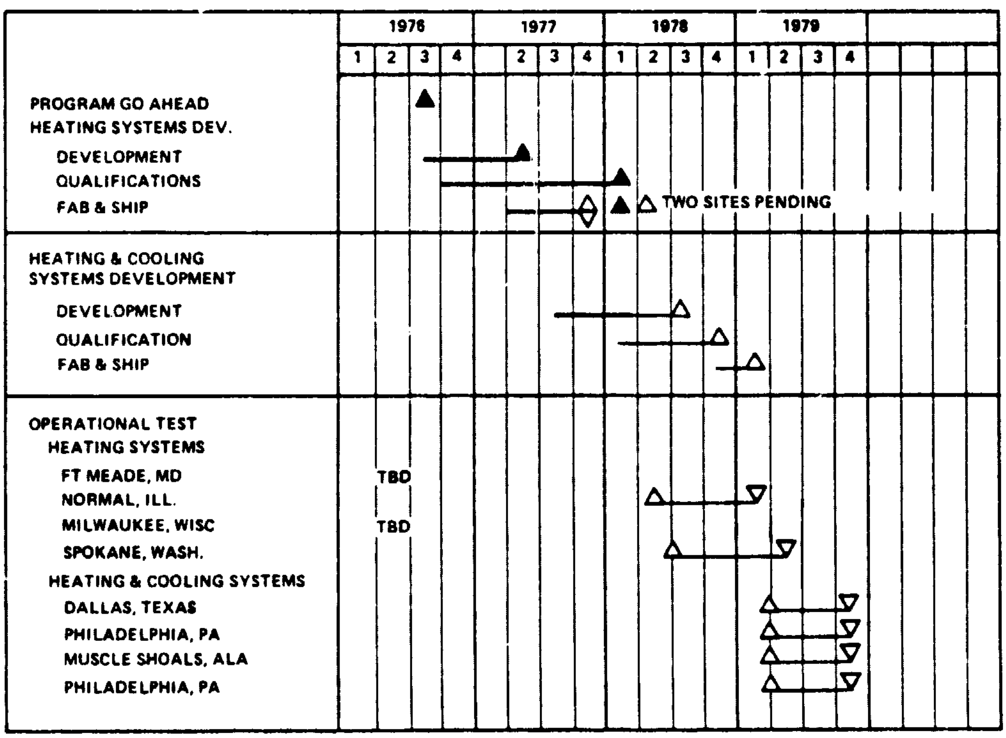


Figure 1-1. Summary Program Schedule

(1) This program is a part of the Department of Energy's activity to develop and demonstrate solar heating and combined heating and cooling systems.

SECTION 2

SYSTEM CONFIGURATIONS

2.1 SOLAR HEATING AND HOT WATER SYSTEMS

Application surveys and performance studies were conducted to arrive at a solar heating and hot water configuration that could be used in a wide variety of applications. The goal was to identify subsystem modules that could be utilized in building-block fashion to adapt standard hardware items to a variety of applications. Typical subsystems are shown in Figure 2-1 which includes the cooling subsystem. The family of solar heating systems is shown in Figure 2-2 for three types of applications. The configurations are similar, with the commercial and multi-family systems involving multiple zones and a central boiler for auxiliary heat. Note that the residential system is compatible with a heat pump installation. A system test to verify the performance of this configuration has been completed at the General Electric Valley Forge test facility and the configuration is being used for the four solar heating and hot water test installations.

Systems of different sizes have been designed to provide the applications designer a selection of pre-engineered systems. This is illustrated in Figure 2-3 for the residential sized systems. Design data is being collected in an application guide that provides the data and tools needed to design a system for a given application.

Features of the heating system include:

- Control of solar collector loop operation based on average insolation level to minimize parasitic power and number of pump starts and maximize amount of energy collected.
- Prepackaged control and auxiliaries (pumps and heat exchangers) for single family residences.
- Families of equipments produced to General Electric specifications.
- Control of energy flow to maximize use of solar energy and minimize use of auxiliary energy
- Compatibility with many types of existing HVAC equipment to minimize the retrofit problem.

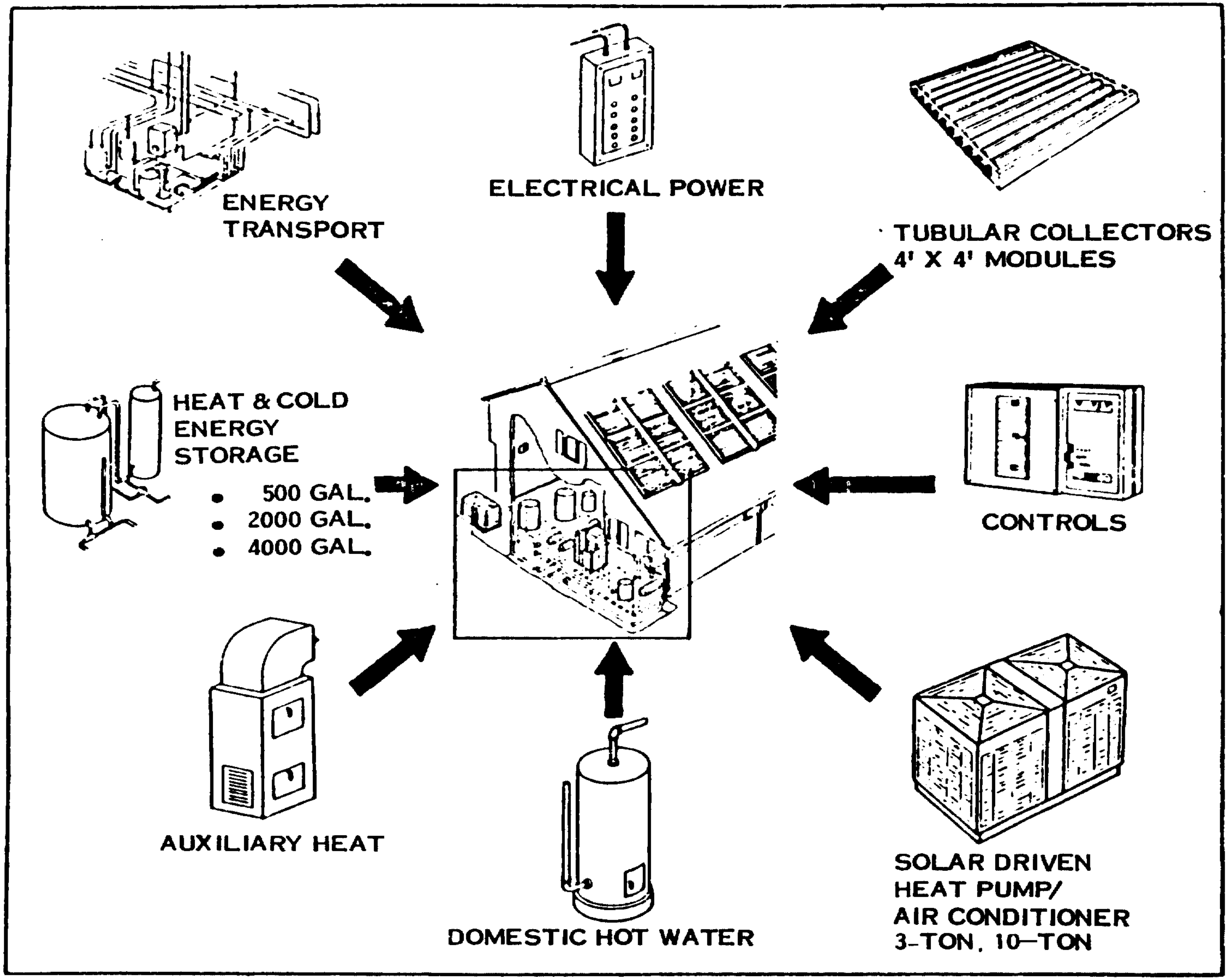


Figure 2-1. Subsystem Building Blocks

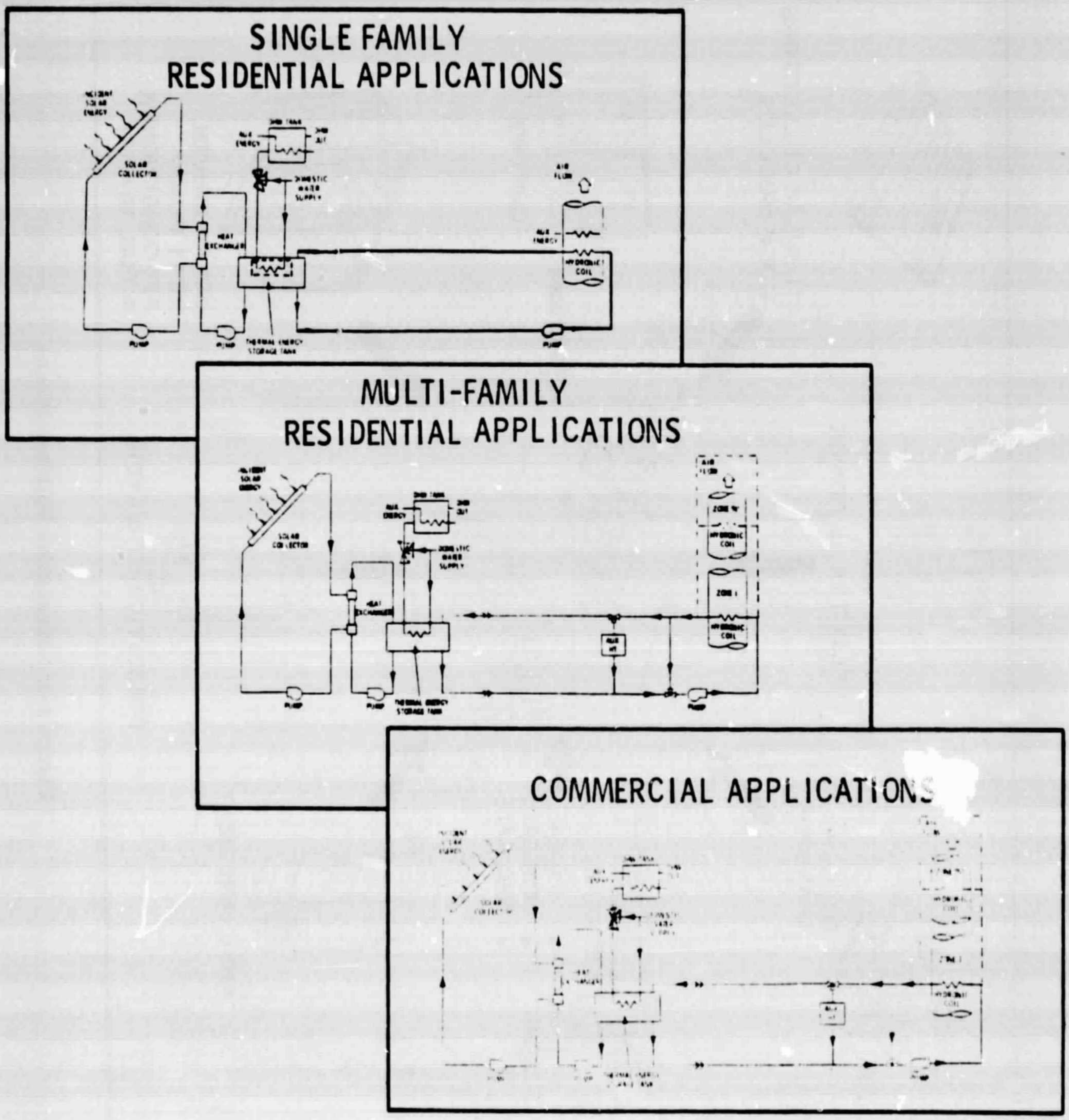


Figure 2-2. Solar Heating System Configurations

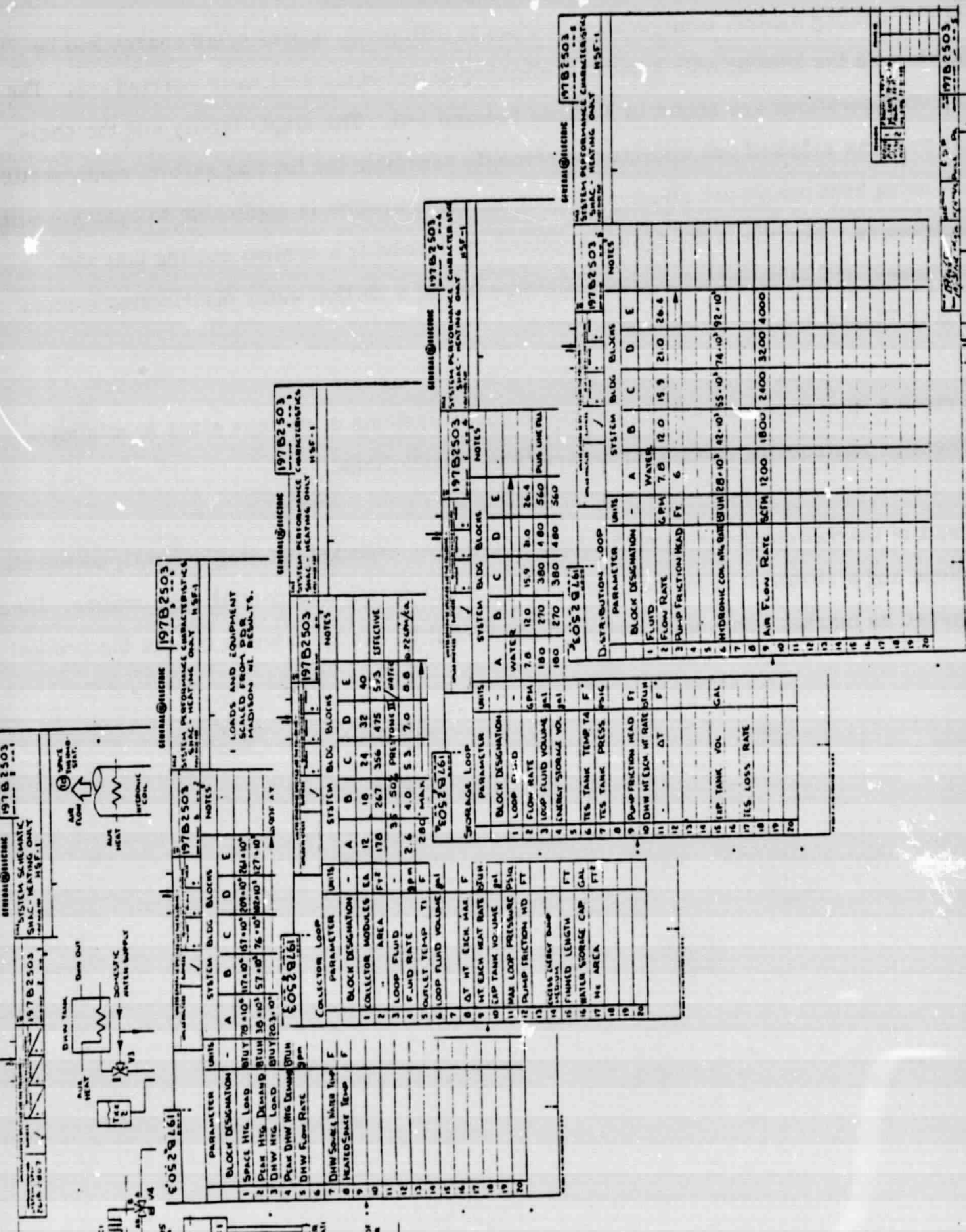


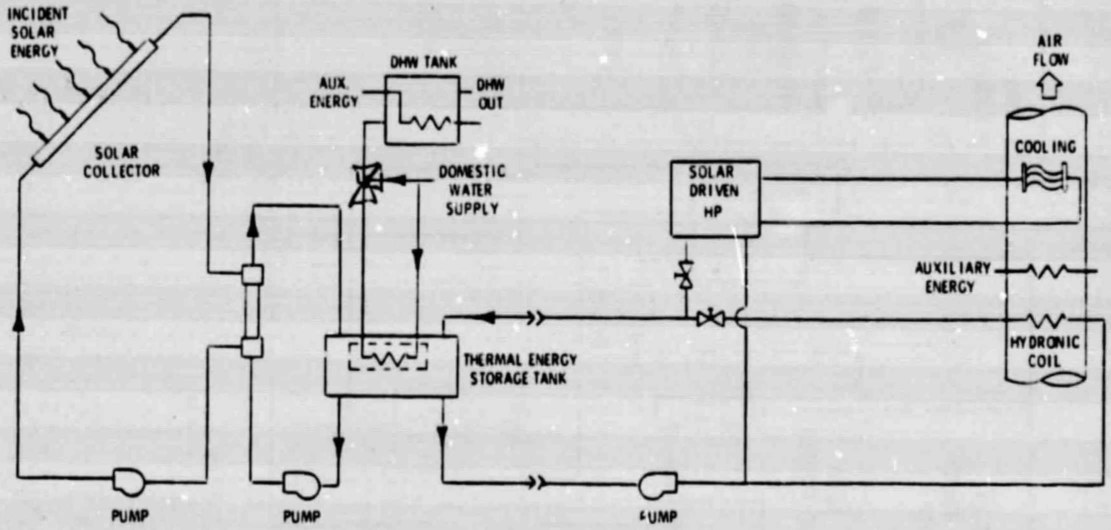
Figure 2-3. Illustration of Pre-engineered Systems (Residential Size)

2.2 SOLAR HEATING, COOLING AND HOT WATER SYSTEMS

Heating and cooling system configuration studies to efficiently utilize solar energy and be compatible with the heating only system configuration and equipment were carried out. The selected configurations are shown in Figures 2-4 and 2-5. The single family and the commercial systems selected are similar and strongly resemble the heating system configurations. Systems using heat pumps are illustrated, but the configuration is applicable to systems with air conditioners. For the multi-family applications involving a central cooling unit and multiple zones, it was found to be more effective to use a chilled water distribution system as shown in Figure 2-5.

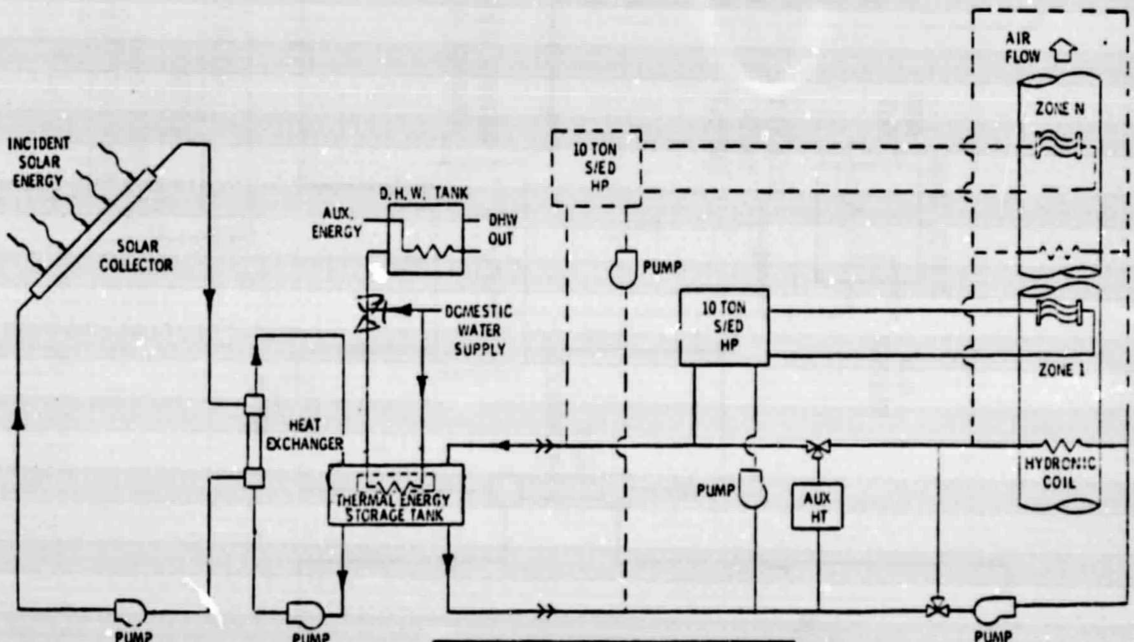
Design studies have been carried out to pre-engineer systems of various sizes to minimize the application engineering needed for a variety of installations.

As a result of market studies a 3-ton heat pump size was selected for single-family residential applications and a 10-ton size for commercial and multi-family residential applications. These are regarded as market entry units and other sizes will be needed later to fill out the product line.



PRIORITY OF OPERATION	
HEATING	COOLING
1. DIRECT SOLAR 2. ELECTRIC HEAT PUMP 3. AUXILIARY ENERGY	1. SOLAR DRIVEN 2. ELECTRIC DRIVEN

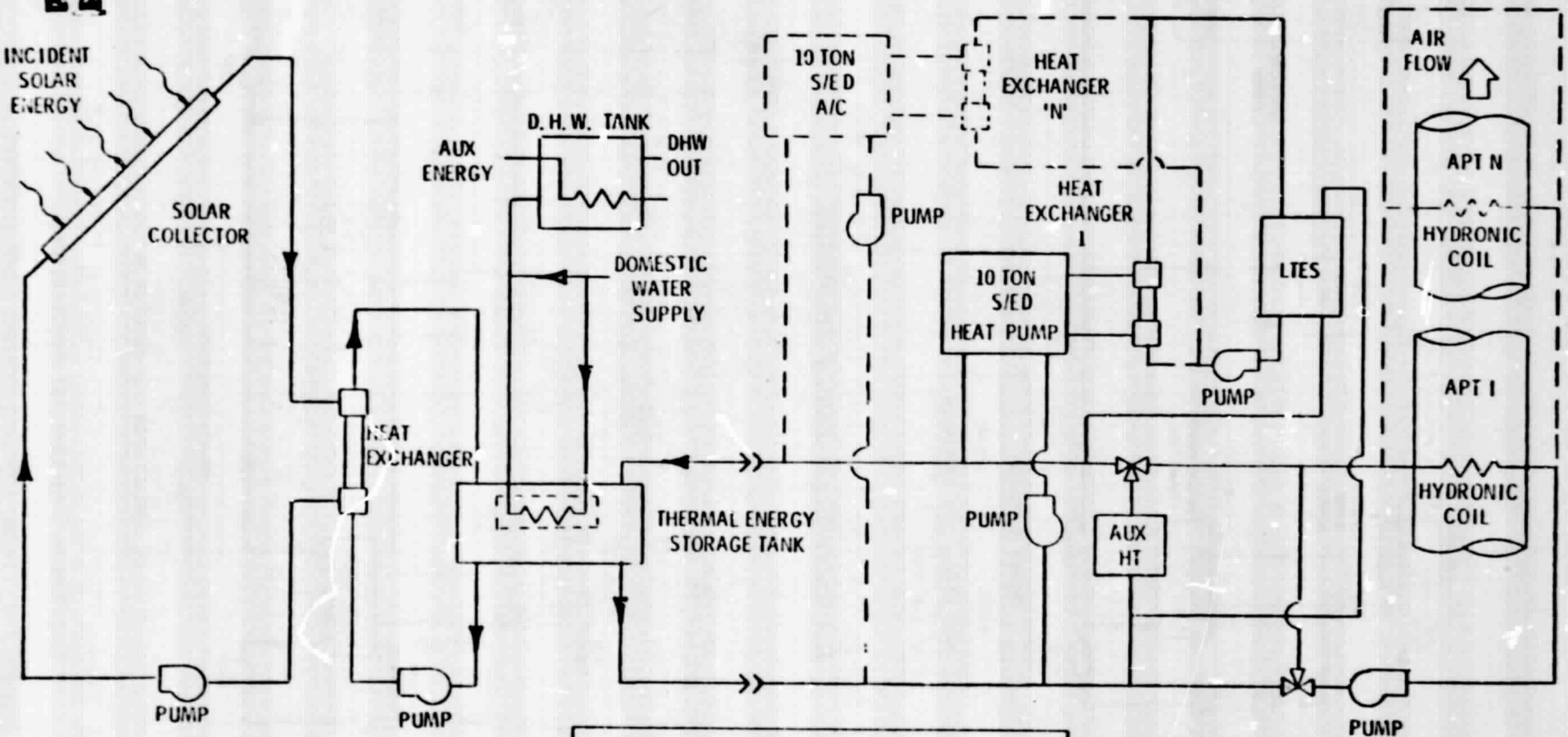
(a) System Configuration Solar Heating, Cooling and Hot Water Single-Family Residential



PRIORITY OF OPERATION	
HEATING	COOLING
1. DIRECT SOLAR 2. AUXILIARY ENERGY	1. SOLAR DRIVEN 2. ELECTRIC DRIVEN

(b) System Configuration Solar Heating, Cooling and Hot Water Commercial Applications

Figure 2-4. Solar Cooling System Configuration



PRIORITY OF OPERATION	
HEATING	COOLING
1. DIRECT SOLAR 2. AUXILIARY ENERGY	1. SOLAR DRIVEN 2. ELECTRIC DRIVEN

Figure 2-5. System Configuration Solar Heating, Cooling and Hot Water Multi-family Residential

SECTION 3
SUBSYSTEM DEVELOPMENT

3.1 SOLAR HEATING AND HOT WATER

3.1.1 SOLAR COLLECTOR

The TC-100 solar collector is being developed to a production-ready design on this contract for use in a variety of applications. This collector provides high efficiency over a wide range of energy collection temperatures, insolation levels, and ambient conditions in a design that can be mass-produced at a low cost. It is shown in Figure 3-1. The collector utilizes evacuated glass tubes, a selective coating, a metal reflector, and a circulating heat transfer fluid entirely contained within metal tubing. (1)

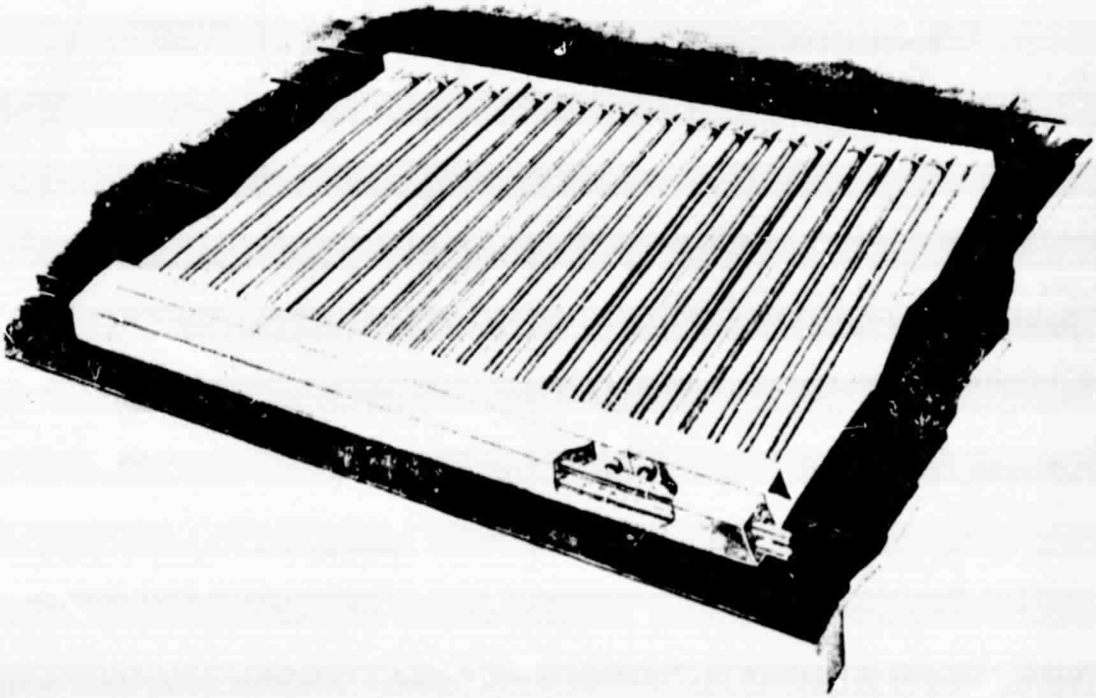


Figure 3-1. TC-100 Vacuum Tube Solar Collector

(1) Information (technical and availability) on the Model TC-100 Vacuum Tube Solar Collector can be obtained from: Manager, Solar Heating and Cooling Marketing, Advanced Energy Programs, General Electric Co., P.O. Box 13601, Philadelphia, Pa. 19101

The performance of the collector is shown in Figures 3-2 and 3-3 and the performance characteristics are listed in Table 3-1. The collector units are approximately 4 foot by 4 foot and include mounting holes at the corners. Mounting brackets and interconnecting fittings are available as accessories. Because its fluid temperature operating range goes to 300°F, the TC-100 solar collector can be effectively used for heating, process heat and cooling applications. Pilot production was initiated in late 1977.

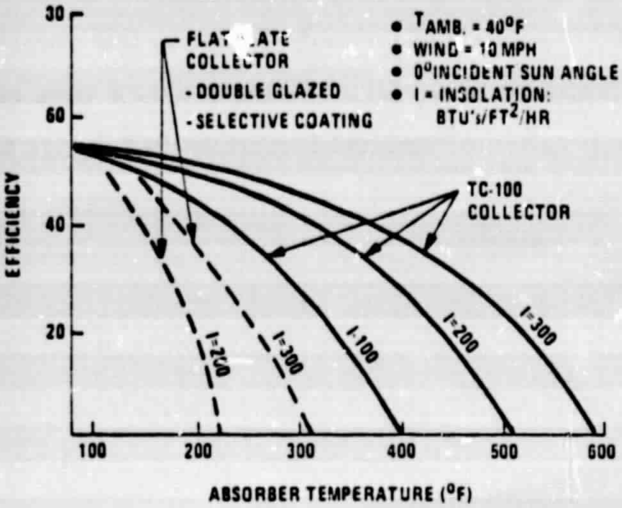


Figure 3-2. Collector Performance

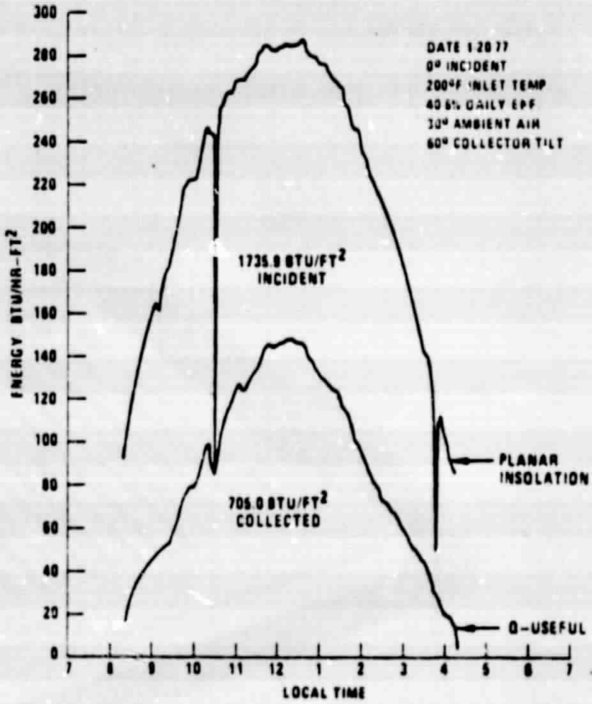


Figure 3-3. Daily Collector Performance Test Results

Table 3-1. Performance Characteristics

- Operational Ambient: -20°F to 140°F
- Operational Fluid Temperature Range: 100°F to 300°F
- ΔP/Collector: Maximum 10 psi @180°F
  Minimum 5 psi
- Maximum Operational Pressure: 70 psia
- Absorber Coating: Selective

The working fluid is a mixture of Prestone II and water. Collector subsystem designs have been prepared which include the circulation pump, the solar collector/energy storage heat exchanger, a radiator component to limit the operating temperatures and pressures, and fluid management components.

3.1.2 CONTROLS

Control logic and hardware have been developed to optimize the performance of the system and to provide needed control functions. Switching functions and control logic are provided by an electrical assembly mounted in the Energy Management Module (Paragraph 3.1.4). The control functions shown in Table 3-2 are provided.

Table 3-2. Heating System Control Functions

Solar Energy Collection	Load Service
• System Off - Insufficient Insolation • Solar Energy Collection and Storage • Solar Energy Rejection. Storage Tank Charged • Restricted Startup - Power failure	• Space Heating - Solar Energy Supplied - Auxiliary Energy Supplied - Off • Domestic Hot Water Preheating - Per available stored energy

The loads are prioritized to utilize solar energy most efficiently and maximize the output of the collector by keeping the use temperature as low as possible.

Conventional immersion temperature switches are used to provide the control signals that are based on thermal energy storage temperature. Two stage thermostats in the residential area provide overall control of the load service by bringing in the auxiliary energy source when there is insufficient solar energy to meet the demand.

A new component was developed to provide solar energy collection control signals as available equipment did not meet system requirements. The vacuum tube collectors have low thermal mass and very low losses. They will reach relativelv high temperatures even with insolation rates so low that useful amounts of energy cannot be collected. Thus, temperature in the collector is not a reliable method for turning on the collector loop. It would turn on because of temperature but flow would lower the temperature because of insufficient insolation and undesirable on-off cycling would occur. These conditions would occur each morning and evening and also could be caused by cloud cover. The sensor provides an average value of insolation and is configured to turn on at the minimum useful level for energy collection based on a time average of the insolation. By analysis the value has been established as 35 Btu/hr-ft^2. The unit, called the solar integrator, is set at this nominal value and can be adjusted. The unit also provides a safety lockout in the event of power failure to prevent thermal shocking of the collector fields. The device, shown in Figure 3-4, mounts on the frame of the solar collector.

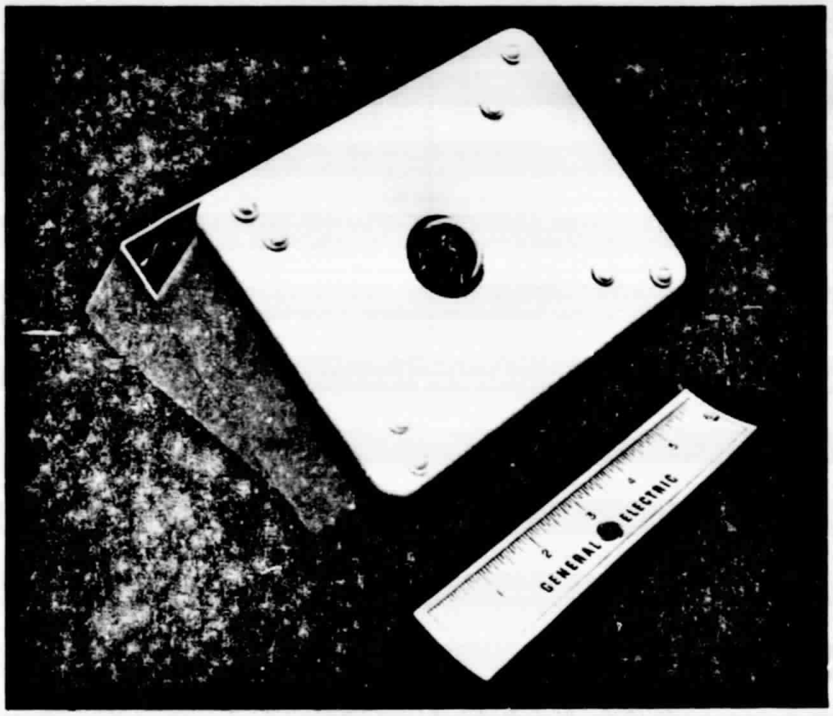


Figure 3-4. Solar Integrator (VF 78-47B)

3.1.3 OTHER COMPONENTS

The functional requirements of otner critical system elements such as pumps, control valves, expansion tanks, tanks for thermal energy storage, fluids, and heat exchangers have been identified and discussed with vendors making these items for commercial markets. This has been done for the range of sizes anticipated for the three types of applications. Specifications have been prepared for use in the procurement of these items.

3.1.4 ENERGY MANAGEMENT MODULE

As a result of investigations of the costs of solar systems, it was concluded that assembling selected elements of the residential size systems at the factory was cost effective. This resulted in the development of an Energy Management Module which included the pumps, control valves, primary heat exchanger, primary loop expansion tank, and electrical controls. A photograph of the unit exhibited at the January ASHRE meeting in Atlanta, Georgia, is shown in Figure 3-5. This unit simplifies the amount of piping that has to be done at the site. The functional definition is given in Figure 3-6.

It was concluded that the EMM concept was not attractive for commercial systems at least for the present. The program approach for these systems is to design each installation with respect to component location and installation.

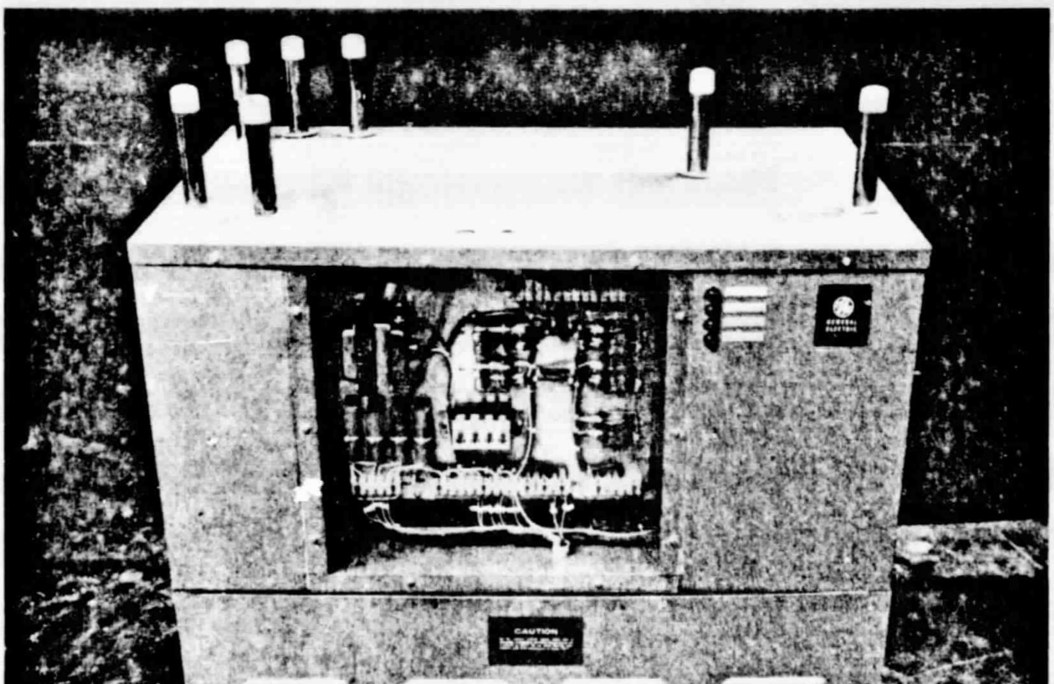


Figure 3-5. Energy Management Module (VF 78-28A)

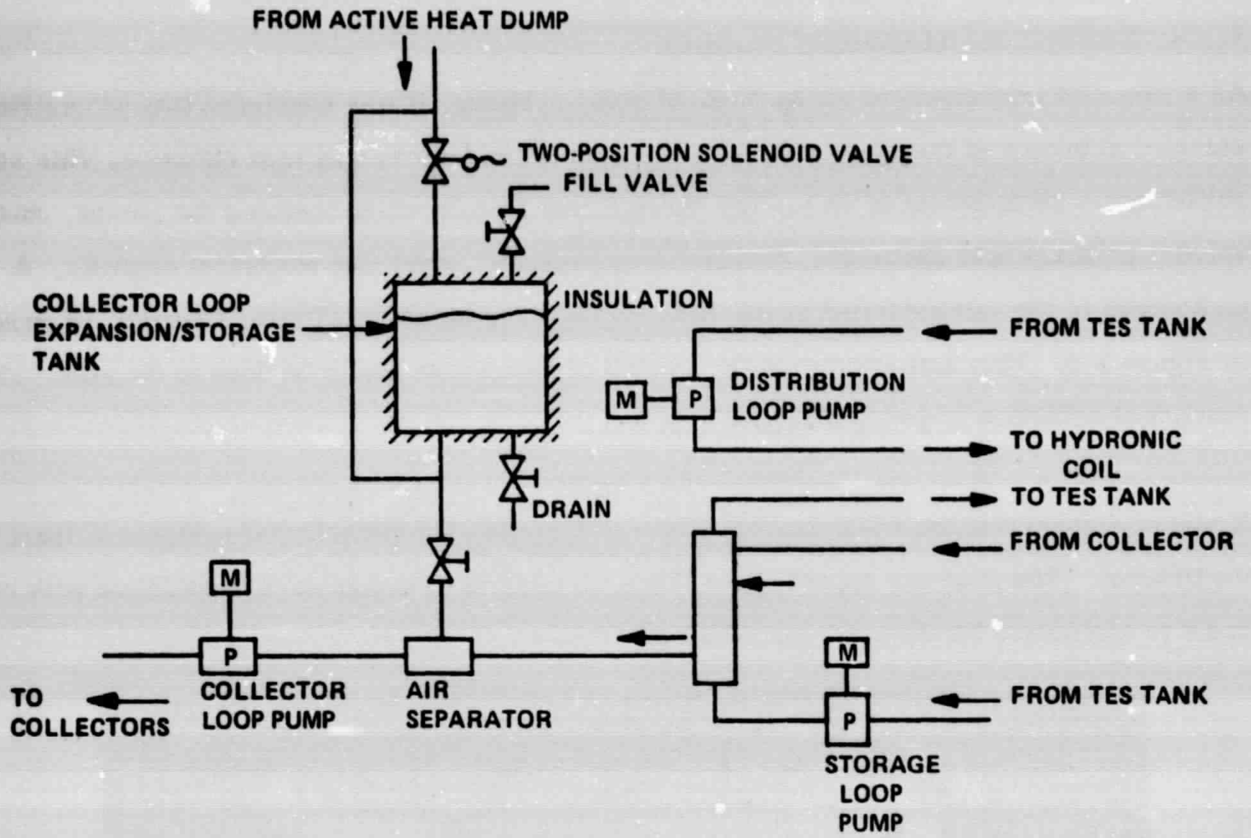


Figure 3-6. EMM Functional Definition

3.1.5 HEATING SYSTEM CONFIGURATION TEST

A heating system configuration test was conducted to verify the performance of the system. The test setup, shown Figure 3-7, utilized an electric heating unit to simulate the energy input of the solar collectors. Thus no solar integrator was used. The system was sized as a large single family residence using solar heating and cooling. Thus a 400 gallon Thermal Energy Storage (TES) tank was used. A commercial type air handler was used to deliver energy to ambient air taken from the solar laboratory at Valley Forge (a high bay industrial building heated and cooled to a comfortable shirt sleeve environment). The heated air was discharged to the same facility. Tests were run with vertical and horizontal TES tanks. The vertical tank is shown in the Figure 3-7. The horizontal tank was installed for testing and then shipped to a residential test site. Because of schedule constraints the test setup utilized line mounted components rather than a prepackaged Energy Management Module.

Test operations verified the performance of the system configuration and provided design data on the location of the TES tank ports and check valves to minimize thermal siphons.

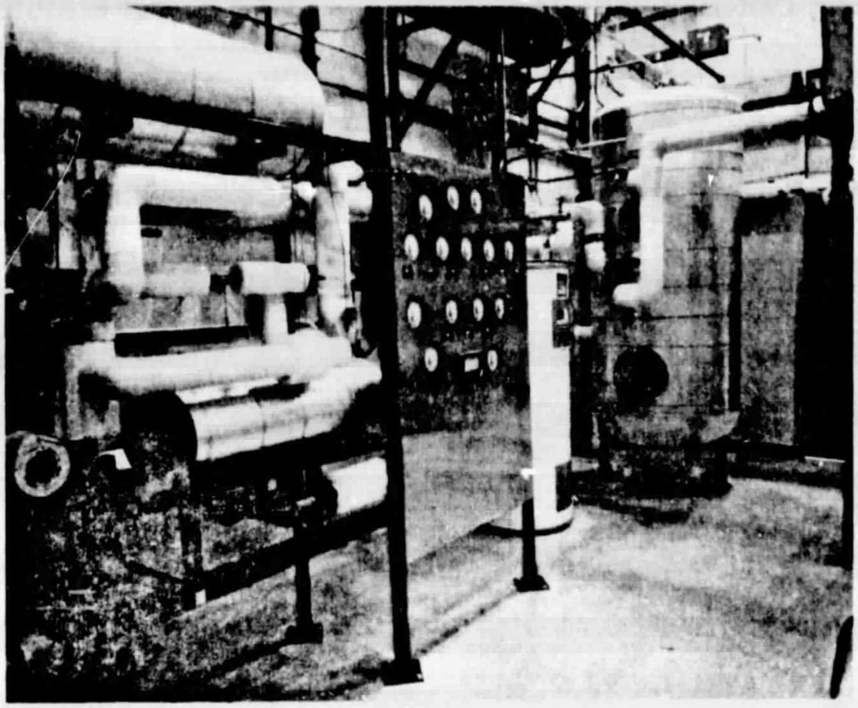


Figure 3-7. Heating System Configuration Test Setup

3.2 SOLAR HEATING, COOLING AND HOT WATER SYSTEMS

3.2.1 INTRODUCTION

As discussed in Section 2 the addition of a solar cooling subsystem does not alter the general nature of the system arrangement. At this time the solar cooling subsystem utilizes higher temperatures than the heating only systems. The increased requirements have been incorporated into functional specifications for the system elements. In many cases the same commercial items used in the heating systems can be used. The control functions are given in Table 3-3.

The principal development activity is the cooling subsystem design and development although the solar collectors are being modified to improve their high temperature performance.

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Table 3-3. Heating and Cooling System Control Functions

Solar Energy Collection	Load Service
• System Off - Insufficient Insolation • Solar Energy Collection and Storage • Solar Energy Rejection - Storage Tank Charged • Restricted Startup - Power Failure	• Space Heating - Solar Energy Supplied - Auxiliary Energy Supplied - Off • Space Cooling - On-Solar Driven - On-Electric Driven - Off • Domestic Hot Water Preheating - Per Available Stored Energy

3.2.2 COLLECTOR DEVELOPMENT

The higher temperature requirements of the current cooling subsystem impact solar collector performance and studies indicated a modified collector would provide improved performances. Thus a modification to the shape of the reflector section and a reduction in the number of vacuum shrouds per module are being incorporated into a collector design. The external dimensions and interfaces are the same as for the TC-100 so the two units will be interchangeable insofar as an installation is concerned.

At this time the design of the modified collectors is complete and test units are being fabricated.

3.2.3 COOLING SUBSYSTEM DEVELOPMENT

The project approach is to develop a solar driven Rankine engine to operate a vapor compression air conditioning machine to provide solar cooling. Electric motor operation will serve as a backup system when insufficient solar energy is available to meet the cooling load. Initially the approach was to deliver prototype units in May 1978, which restricted the time available for development and resulted in the use of available technology for many of the key system elements. The system had a peak operating temperature of 250°F, utilized water evaporation to reduce the condensing temperature of the engine and air conditioner compressor, and had an open air conditioning compressor. The air conditioning cycle utilized R-22, while the solar engine working fluid was R-11. The development was completed through fabrication, and checkout of the 3-ton breadboard test unit is shown in Figure 3-8.

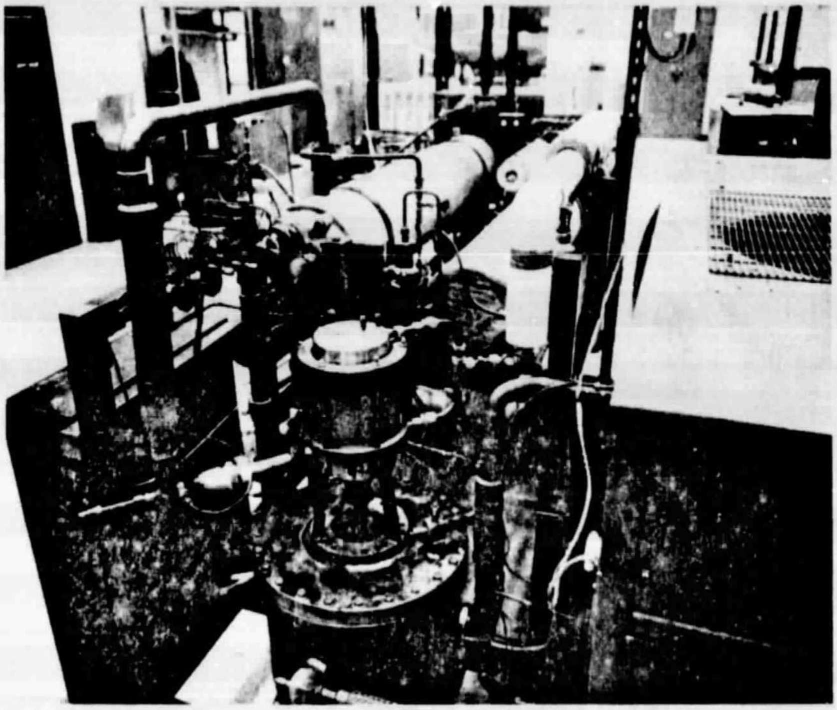

Figure 3-8. Rankine/Electric Heat Pump

As a result of marketing and application studies after contract start, it was concluded that the prototype units would not include important marketing features and that the evolution of the market would allow a longer development cycle. Consequently, the design approach for the solar cooling system has been modified to include the following features:

1. A hermetically sealed system.
2. Air side condensers; thereby eliminating the evaporative cooling utilized in the original approach.

The temperature of the system has been increased to maintain performance at the higher condensing temperatures. At this time the design process is underway with the following design selections:

1. Engine Working Fluid - FC-88
2. Maximum Engine Working Fluid Temperature - 300°F
3. Heat Pump Working Fluid - R-22
4. Clutch/Magnetic Drive.

The cooling subsystem is being developed in two sizes - 3 ton and 10 tons. A schematic diagram of the units is shown in Figure 3-9. Detail design of the system elements is underway. The units feature the General Electric developed multi-vane expander. This is a high efficiency self starting prime mover that can be directly coupled to commercial heat pump compressors. The system uses two fluids with each fluid loop hermetically sealed. A magnetic drive transfers torque across the diaphragm that separates the two fluids.

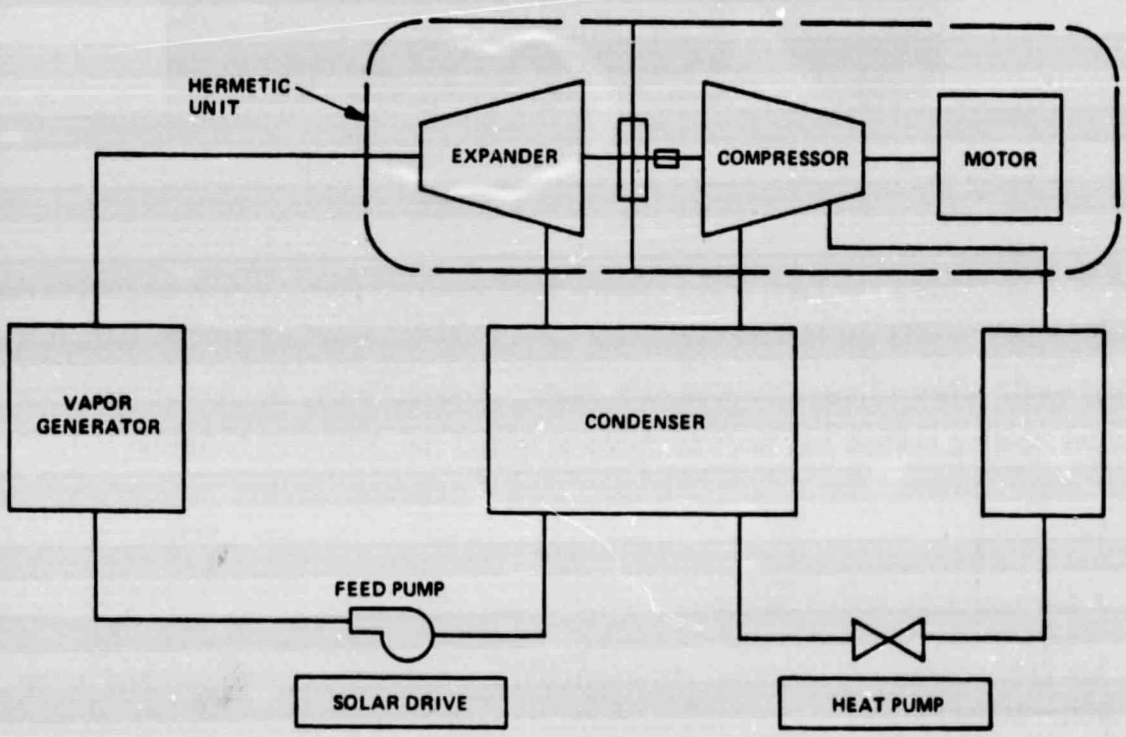

Figure 3-9. Rankine/Electric Heat Pump Schematic

The general appearance of the 3-ton outdoor unit is shown in Figure 3-10. Appearance design of the 10-ton unit is underway.

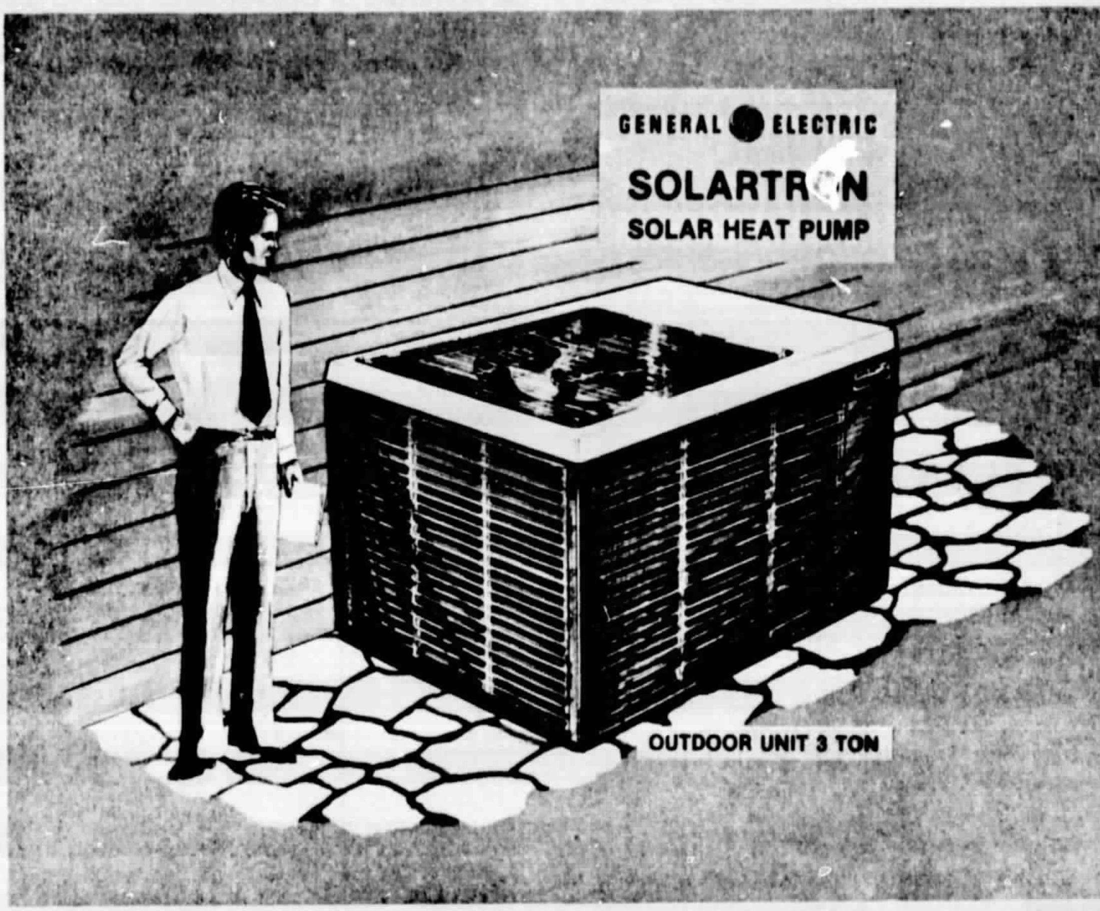

Figure 3-10. Three Ton Solar/Electric Heat Pump Outdoor Unit

SECTION 4

OPERATIONAL TEST

4.1 INTRODUCTION

The current plan for the prototype systems to be installed in Operational Test Sites on this project is given in Table 4-1. Each will be equipped with NASA provided sensors and data processing equipment so that performance can be monitored. Monthly evaluations of each sites' performance will be made.

Table 4-1. Operational Test Site Summary

System Type	Location	Application	Nominal Collector Area (ft^2)	TES Size (gal)	Time of Install.
Heating-Single Family	Normal, Ill.	Farm House	320	400	Feb '78
Heating-Single Family	TBD	Residence	TBD	TBD	TBD
Heating-Commercial	TBD	TBD	TBD	TBD	TBD
Heating-Commercial	Spokane, Wash.	YWCA	4800	6750	April '78
Heating and Cooling-Single Family	Dallas, Texas	Residence	384	400	March '79
Heating and Cooling-Single Family	TBD	Residence	384	400	TBD
Heating and Cooling-Commercial	Muscle Shoals, Ala.	Records Center	1280	1800	March '79
Heating and Cooling-Commercial	TBD	TBD	1280	1800	TBD

Originally 12 sites were planned but the four multi-family sites were cancelled prior to ordering hardware for any of them. Two sites identified for the heating system have been cancelled because of costs/difficulties associated with the retrofit installations.

4.2 NORMAL ILLINOIS FARMHOUSE

The system installed in the Normal, Illinois, site is a conventional retrofit application in a residence with fuel oil fired, hot air system and electric heated hot water. The TES tank, EMM and data system are installed in the basement and the collectors are on a dormer added to the frame structure. The collector installation is shown in Figure 4-1. At the time of the photo the system had not been completed and the collectors are covered with clear mylar. A schematic diagram for the system is shown in Figure 4-2.

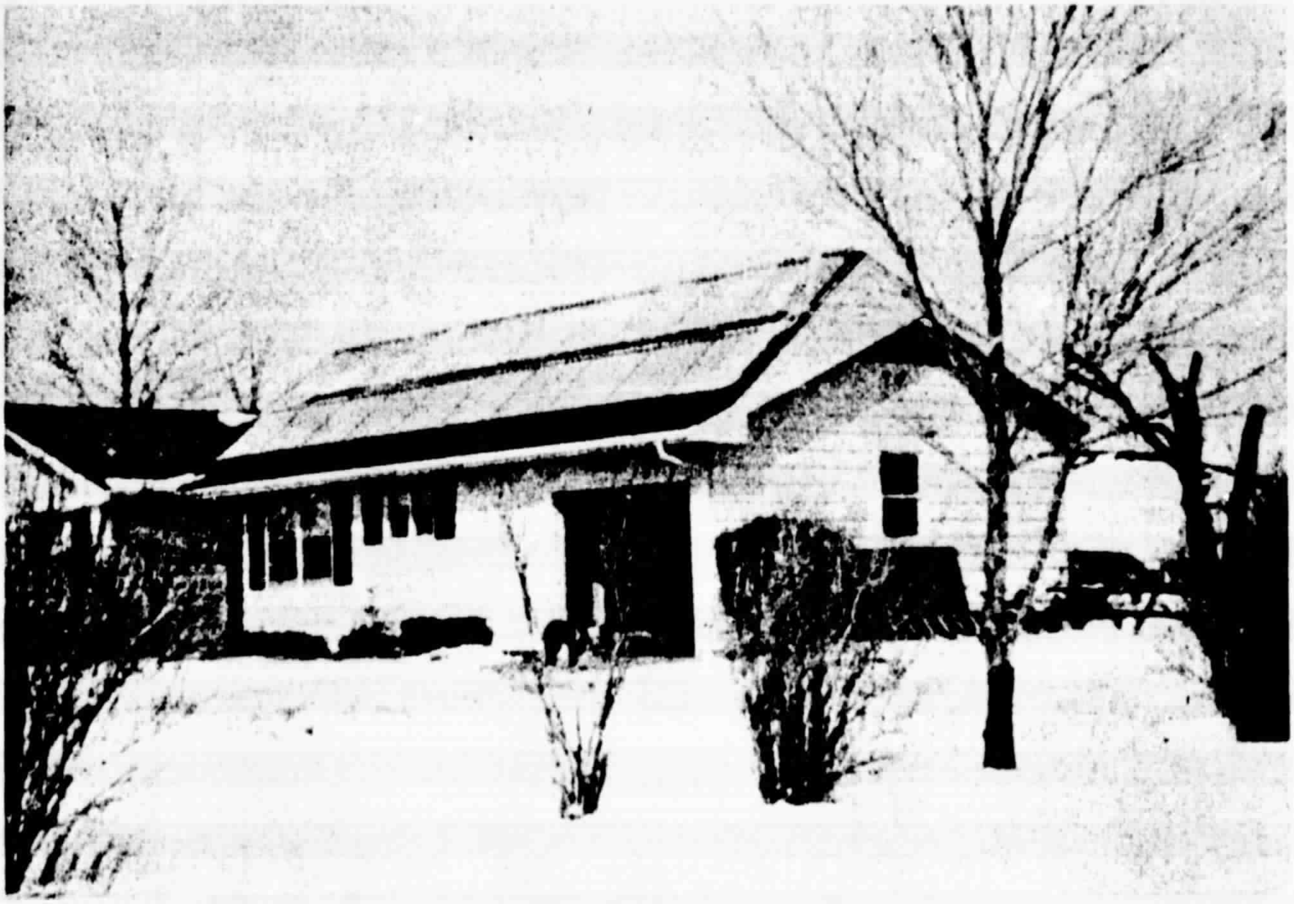

Figure 4-1. Collector Installation at Normal, Illinois

4.3 SPOKANE YWCA

The system is being installed at the time of this report. The system schematic is shown in Figure 4-3. The application is unusual in that heat is provided to a swimming pool to warm it for therapeutic purposes when energy is not required for space heating. The TES tank is installed in a small shelter added to the building. In other respects the installation is typical of a solar system added to selected zones of an existing multizone hot water heating system

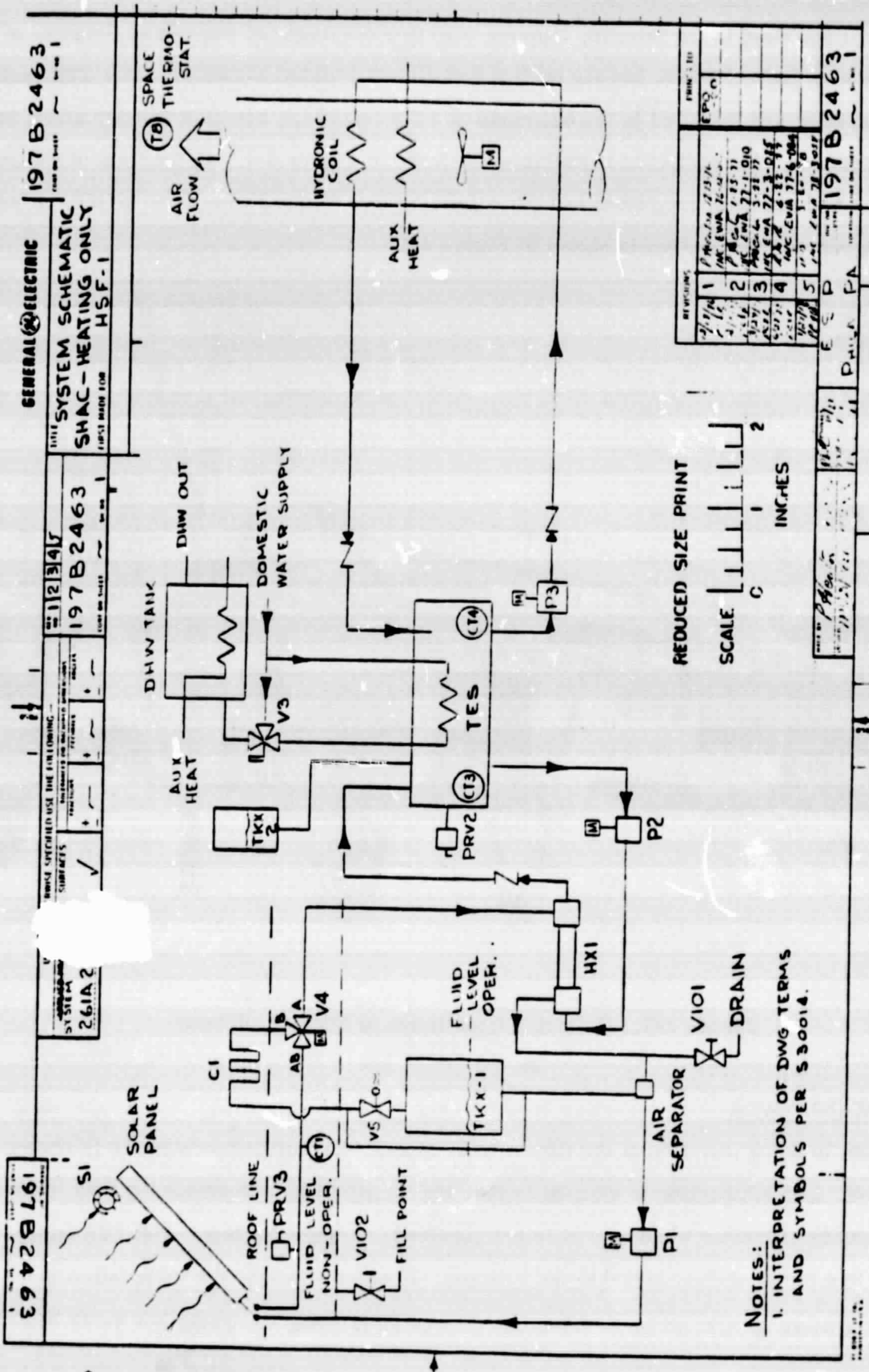

Figure 4-2. Schematic Diagram for Normal, Illinois (Farmhouse System)

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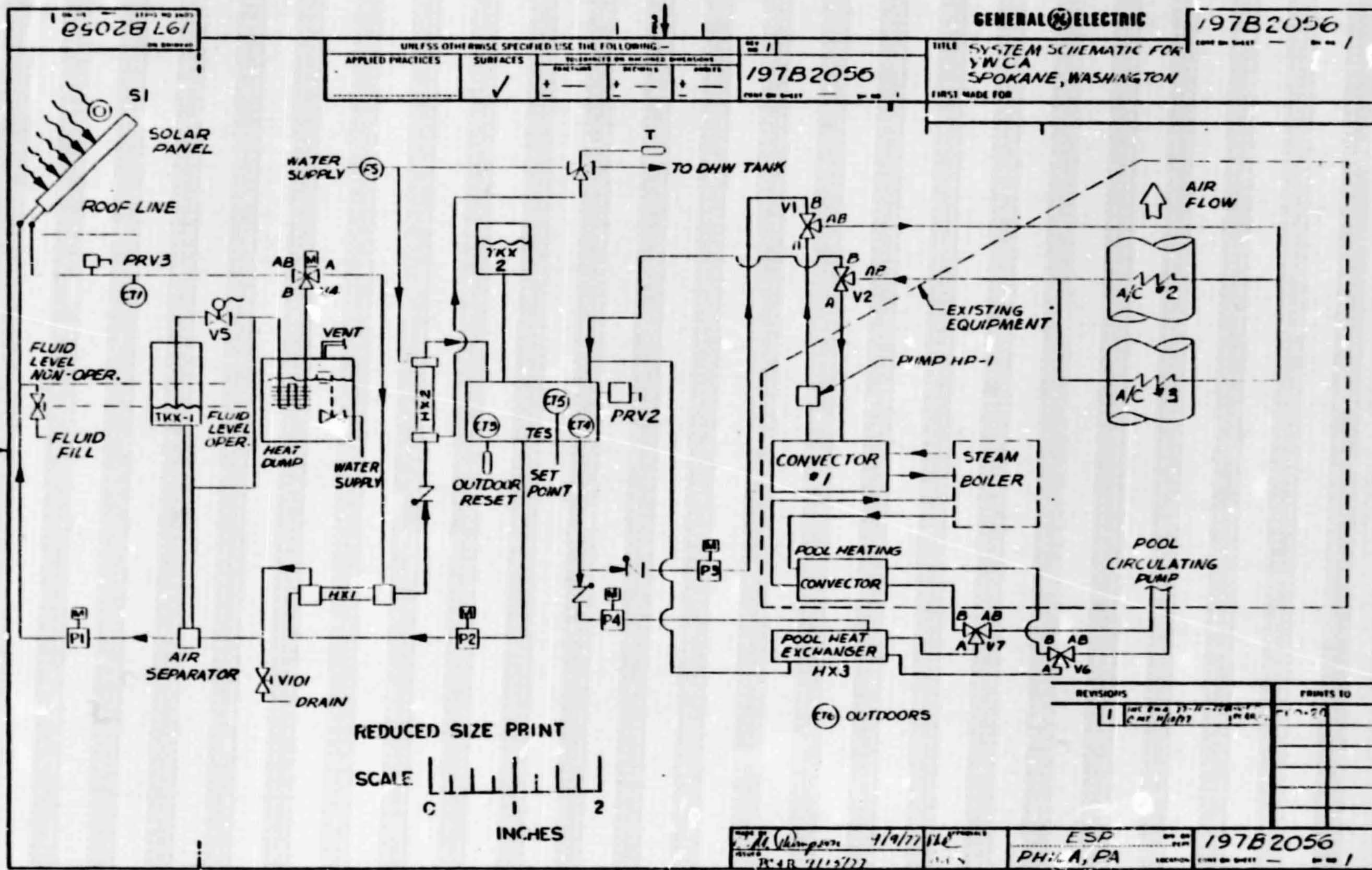

Figure 4-3. Schematic Diagram for Spokane YWCA System

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